Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: MAC Layer Concepts for THz Communications
Date Submitted: 17 March, 2013
Source: Sebastian Priebe, Technische Universität Braunschweig
Address: Schleinitzstraße 22, D-38106 Braunschweig, Germany
Voice: +49-531-391-2417, FAX: +49-531-391-5192, E-Mail: priebe@ifn.ing.tu-bs.de

Abstract: Wireless THz radio networks will, alike any other digital data transmission system, need an appropriate Medium Access Control protocol definition, which has not been subject to any discussions in the Interest Group THz yet. Hence, this document identifies the basic requirements for a THz MAC layer to be fulfilled. Those requirements differ significantly from conventional wireless data communications systems and depend highly on the use cases of THz radio, as is illustrated. Moreover, the document addresses the potential reuse of established MAC protocol definitions forTHz communications and names required amendments, where applicable.

Purpose: Basis for discussion of appropriate MAC layer concepts for THz communications

MAC Layer Concepts for THz Communications

Sebastian Priebe[1]

[1] Institut für Nachrichtentechnik, Technische Universität Braunschweig, Germany

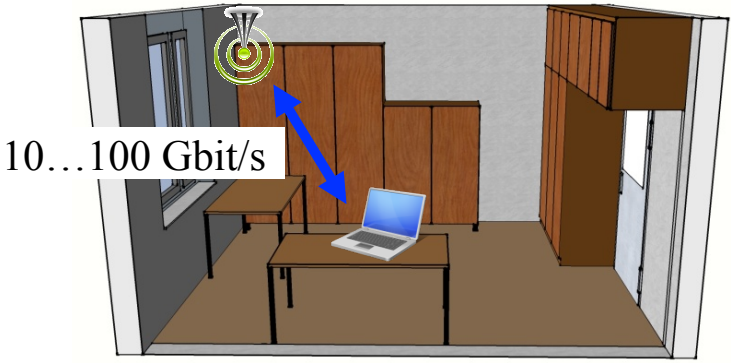
Outline

1. **Introduction**
2. General MAC Layer Requirements
3. Use-Case-Specific MAC Requirements
4. Suitability of Existing IEEE MAC Protocols
5. Conclusion

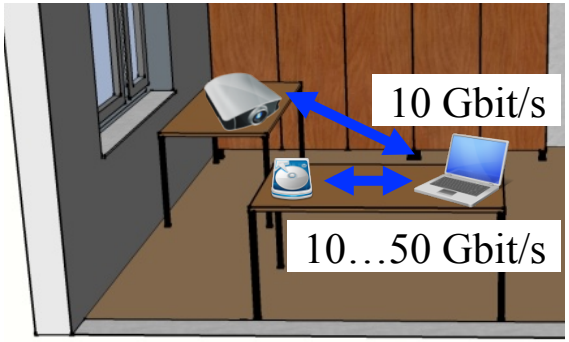
Introduction (1)

Steps so far:

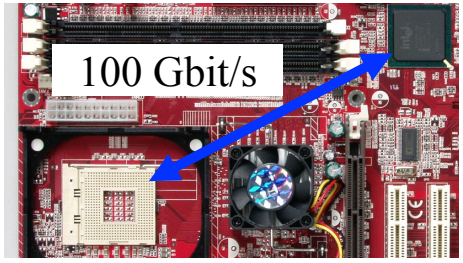
1. Identification of use cases (amongst others):



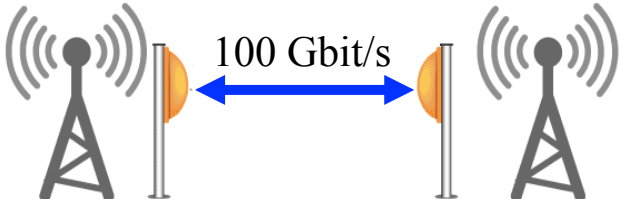
(1) THz WLANs



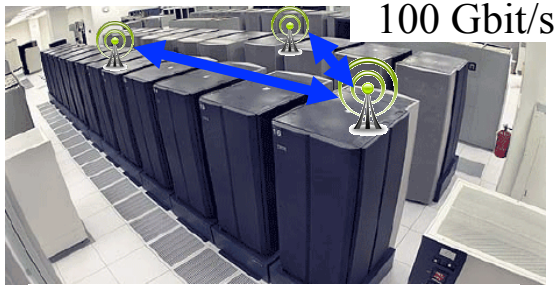
(2) THz WPANs



(3) Chip-to-chip links



(4) Fixed links

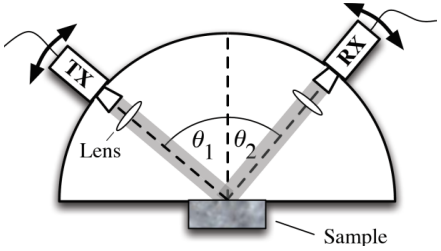


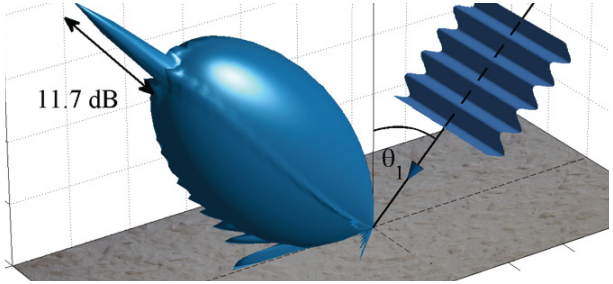
(5) Data center links

Introduction (2)

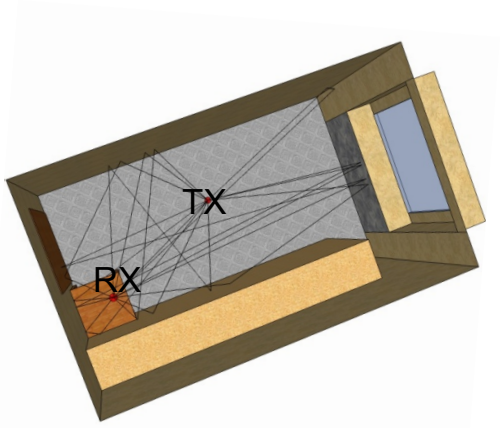
2. Characterization and modeling of the THz radio channel:

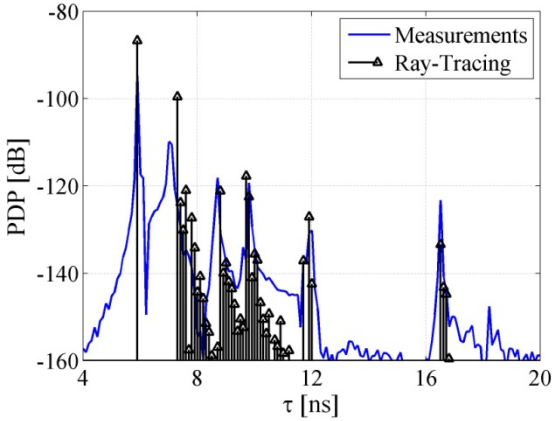
a) Propagation investigations:





b) Indoor channel measurements:

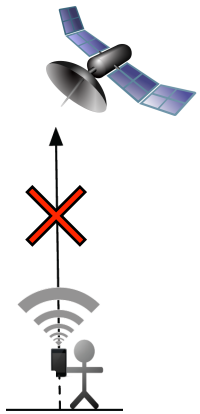




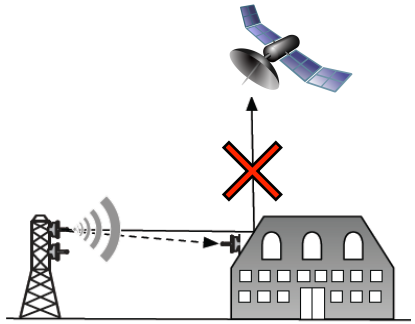
→ Analytical propagation models
→ Validated ray tracing propagation simulator

Introduction (3)

3. Studies on the interference of THz communications with passive Earth exploration services:



1.) Outdoor-operated TX



2.) Fixed links

3.) Airborne-operated TX

→ Interference mitigation schemes can help avoiding interference completely

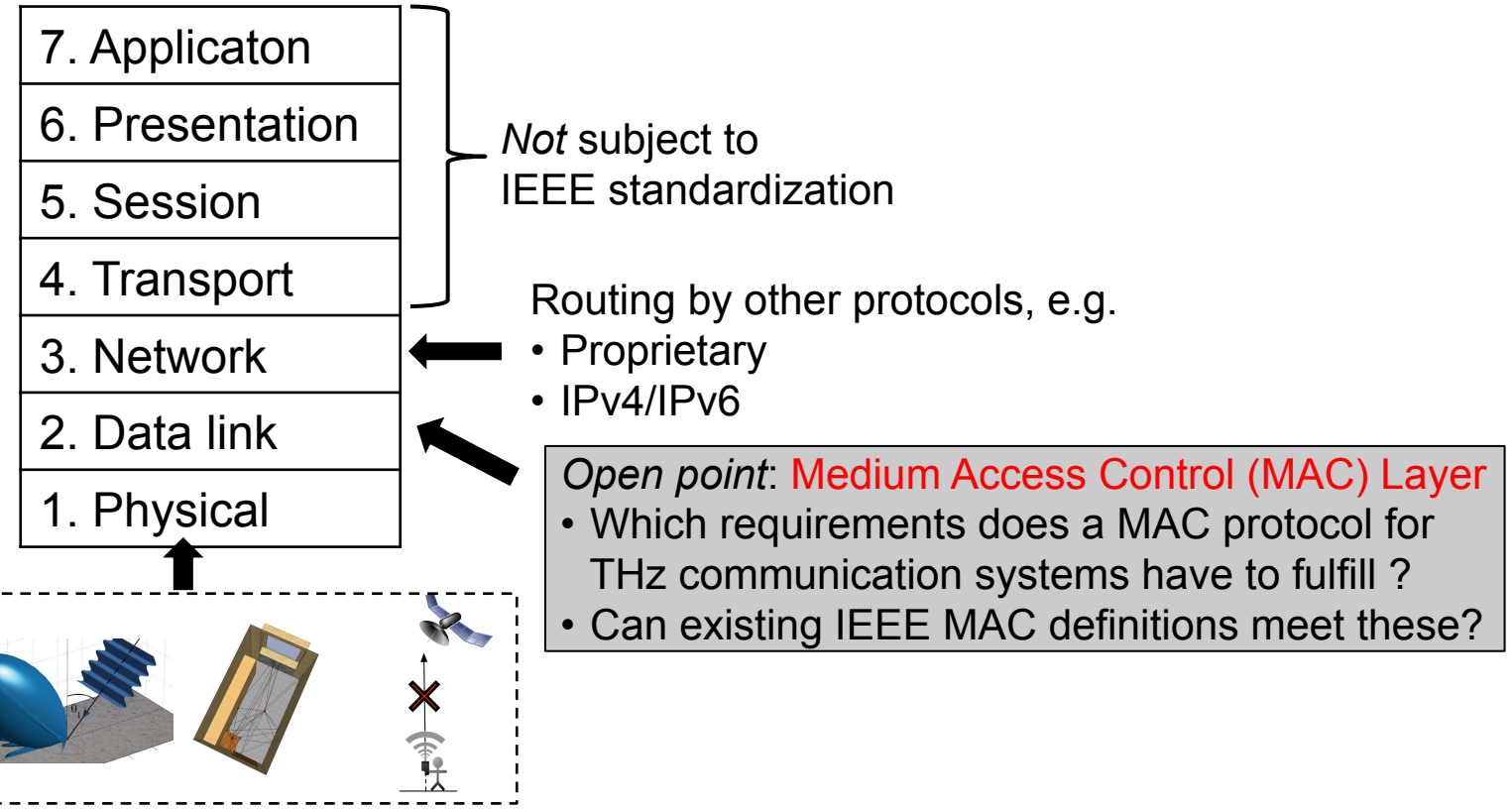
- *Up to now*: good understanding of the physical layer requirements
- *Next*: consideration of the Medium Access Control layer

IEEE doc.15-12-0324-00-0thz_Interference_between_THz_Communications_and_Spaceborne_Earth_Exploration_Services

Introduction (4)

Definition of a complete THz radio system standard:

OSI model layers:



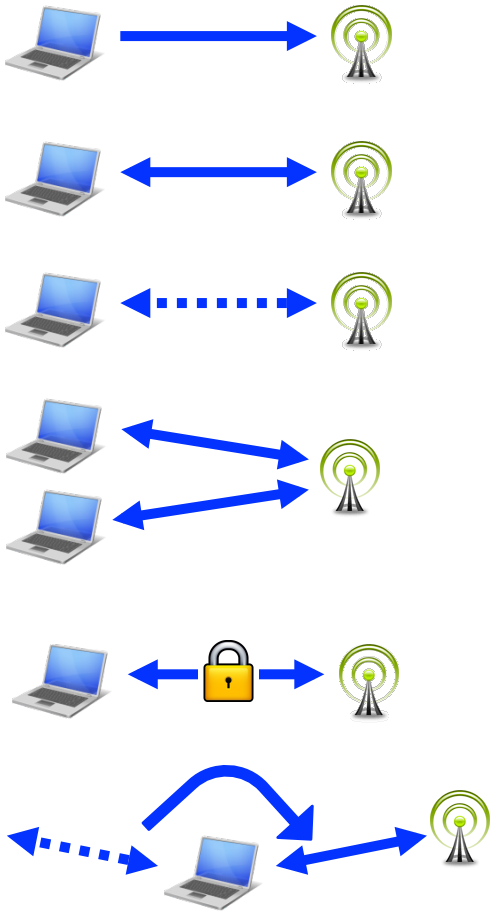
Outline

1. Introduction
2. **General MAC Layer Requirements**
   - **MAC Functions**
   - **Out-of-Band Signaling**
3. Use-Case-Specific MAC Requirements
4. Suitability of Existing IEEE MAC Protocols
5. Conclusion

MAC Functions (1)

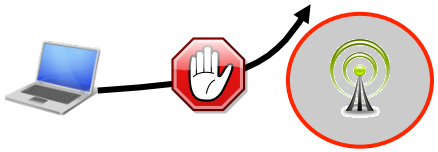
The MAC layer must support:

- Access/association
- Data transmission
- Disassociation
- Multiple clients
- Security
- Roaming

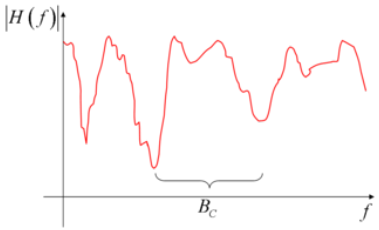


MAC Functions (2)

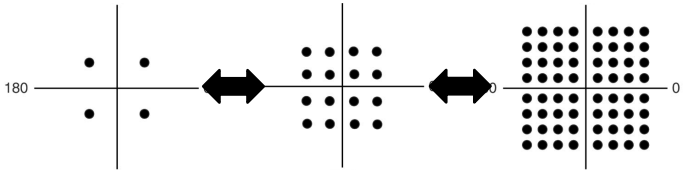
- Admission control



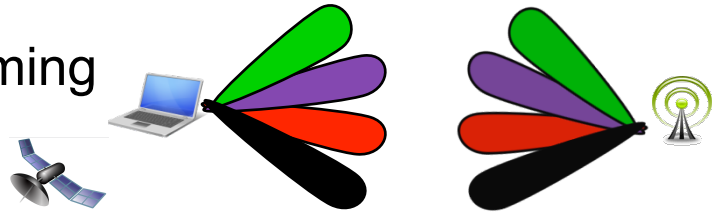
- Channel estimation



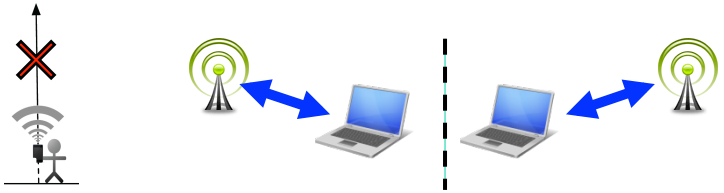
- Adaptive modulation



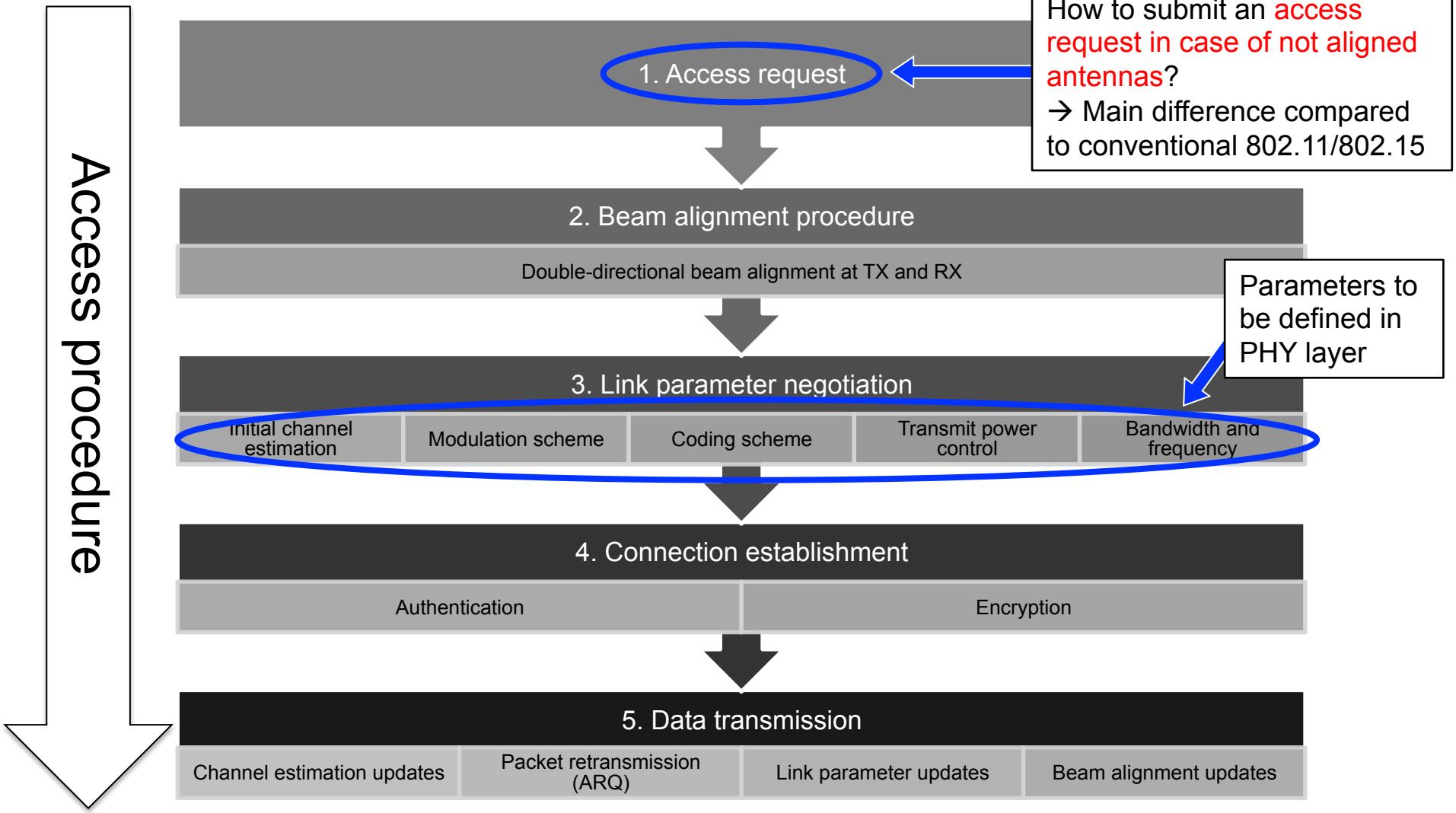
- Control of beamswitching/-steering/-forming



- Interference cancellation/coexistence

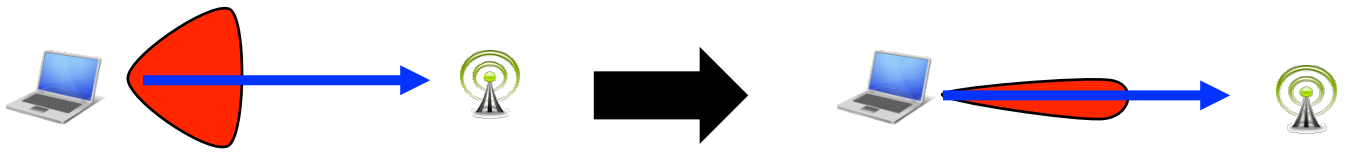


MAC Functions (3)



Out-of-Band Signaling (1)

- *Problem:* Access request transmission in the THz band not possible in case that antennas are not aligned
- How does IEEE 802.15.3c solve this issue?
  - Iterative scanning procedure:



1.) Begin with a broad, quasi-omnidirectional beam

2.) Increase directivity and refine beam direction

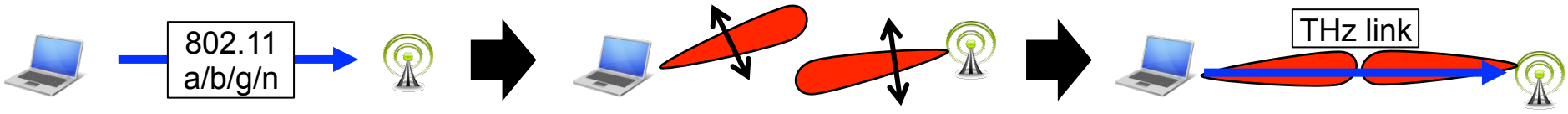
→ Unfeasible at THz frequencies because of very high propagation losses and low output powers

- *Idea*: Access signaling for the THz link over an additional conventional WLAN channel

Out-of-Band Signaling (2)

Procedure

1. Access request via conventional 802.11a/b/g/n WLAN, UWB or any other radio system with omnidirectional antennas
2. Initiation of beam scanning
   - Coordinated scanning by TX and RX
   - If possible initial rough direction estimation with UWB or 802.11n MIMO



1.) Access and beam scanning request

2.) Iterative, coordinated scanning of the THz beams by TX and RX

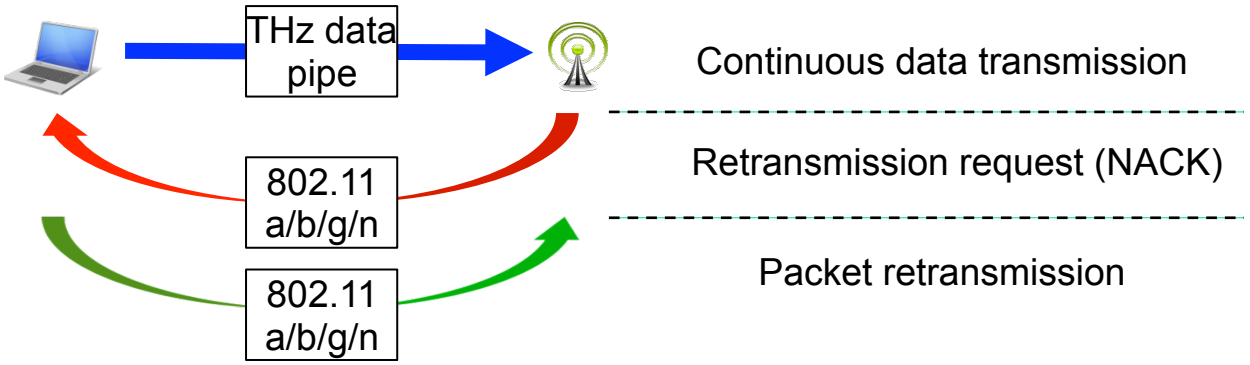
→ Control information exchange via conventional WLAN link

3.) Data transmission over THz link

→ Optimum beam alignment possible despite high directivites

Out-of-Band Signaling (3)

3. *Optional*: Retransmission of corrupt packages via conventional WLAN Link



- Advantages:
  - \+ THz link for ultra fast, non-disrupted data transmission
  - \+ ARQ manageable via simple data transmission over the conventional WLAN
  - \+ No complex ARQ necessary in the THz MAC framework
- Disadvantage:
  - – Very large buffers required due to potential latencies

Outline

1. Introduction
2. General MAC Layer Requirements
3. **Use-Case-Specific MAC Requirements**
   - **Use Case Radio Channel Conditions**
   - **Implications on the MAC Layer**
   - **Special Requirements of the Use Cases**
4. Suitability of Exisiting IEEE MAC Protocols
5. Conclusion

Use Case Radio Channel Conditions

	1.) Fixed links	2.) Data center links	3.) Intra device	4.) Kiosk	5.) WPAN	6.) WLAN
Multipath propagation	None		High; sup-pressible	Low	Medium-high	
Dynamics	None			Low	Medium	
Control over environment and TX/RX placement	High			Medium	None	
Beam alignment	Once during setup; manual			Not necessary	Initial alignment and tracking; automatic	
Multiple stations	No	Yes, time multiplex	No	No	Yes	
Access	Possible in THz band			Via conventional radio technology		

Type (a): No dynamic beam alignment, THz access, point-to-point

Type (b): Type (a) + conventional radio access

Type (c): Dynamic beam alignment, conventional access, multi-user

Implications on the MAC Layer

	1.) Fixed links	2.) Data center links	3.) Intra device	4.) Kiosk	5.) WPAN	6.) WLAN
Access						
Data transmission						
Disassociation						
Security						
Roaming						
Admission control						
Channel estimation						
Adaptive modulation						
Beam control						
Coexistence						

Secondary access technology

Very simple MAC scheme sufficient

Hardware encryption

More complex MAC layer functions necessary

Necessary

Not necessary

Special Requirements of the Use Cases

1. *Fixed links*: bit transparent transmission for the wireless extension of wired 40 Gbit/s or 100 Gbit/s links
2. *Data center links*: transmission on demand, flow control and switch between multiple, predefined RX stations
3. *Intra device*: transparent connection, very low protocol processing overhead desirable
4. *Kiosk downloads*: fast and reliable association/disassociation
5. *WPANs*: ad-hoc network functionality
6. *WLANs*: robust operation, IEEE 802.11a/b/g/n user experience

Outline

1. Introduction
2. General MAC Layer Requirements
3. Use-Case-Specific MAC Requirements
4. **Suitability of Existing IEEE MAC Protocols**
   - **IEEE 802.3 (Ethernet)**
   - **IEEE 802.11**
   - **IEEE 802.15.3c**
   - **Recommendations**
5. Conclusion

IEEE 802.3 (Ethernet)

- Basic frame structure:

Preamble	Start frame delimiter	Destina-tion address	Source address	Length	Data	Frame check sequence
7 bytes	1 byte	6 bytes	6 bytes	2 bytes	45-1500 bytes	4 bytes

- Access scheme: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

→ TX listens for other frames and transmits only if medium is free

- Packet corruption test utilizing checksum

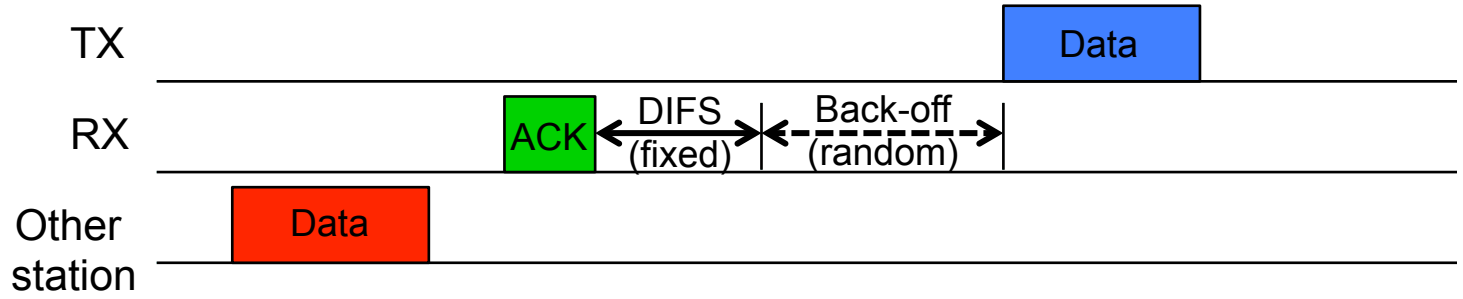
→ Retransmission request in case of errors

IEEE 802.11 (1)

- Basic structure of 802.11:

<table>
<tr><td colspan="8">802.2 Logical Link Control</td></tr>
<tr><td>802.3 MAC</td><td colspan="7">802.11 MAC</td></tr>
<tr><td>802.3
PHY</td><td>802.11
FHSS</td><td>802.11
DSSS</td><td>802.11a</td><td>802.11b</td><td>802.11g</td><td>802.11n</td><td>802.11ad</td></tr>
</table>

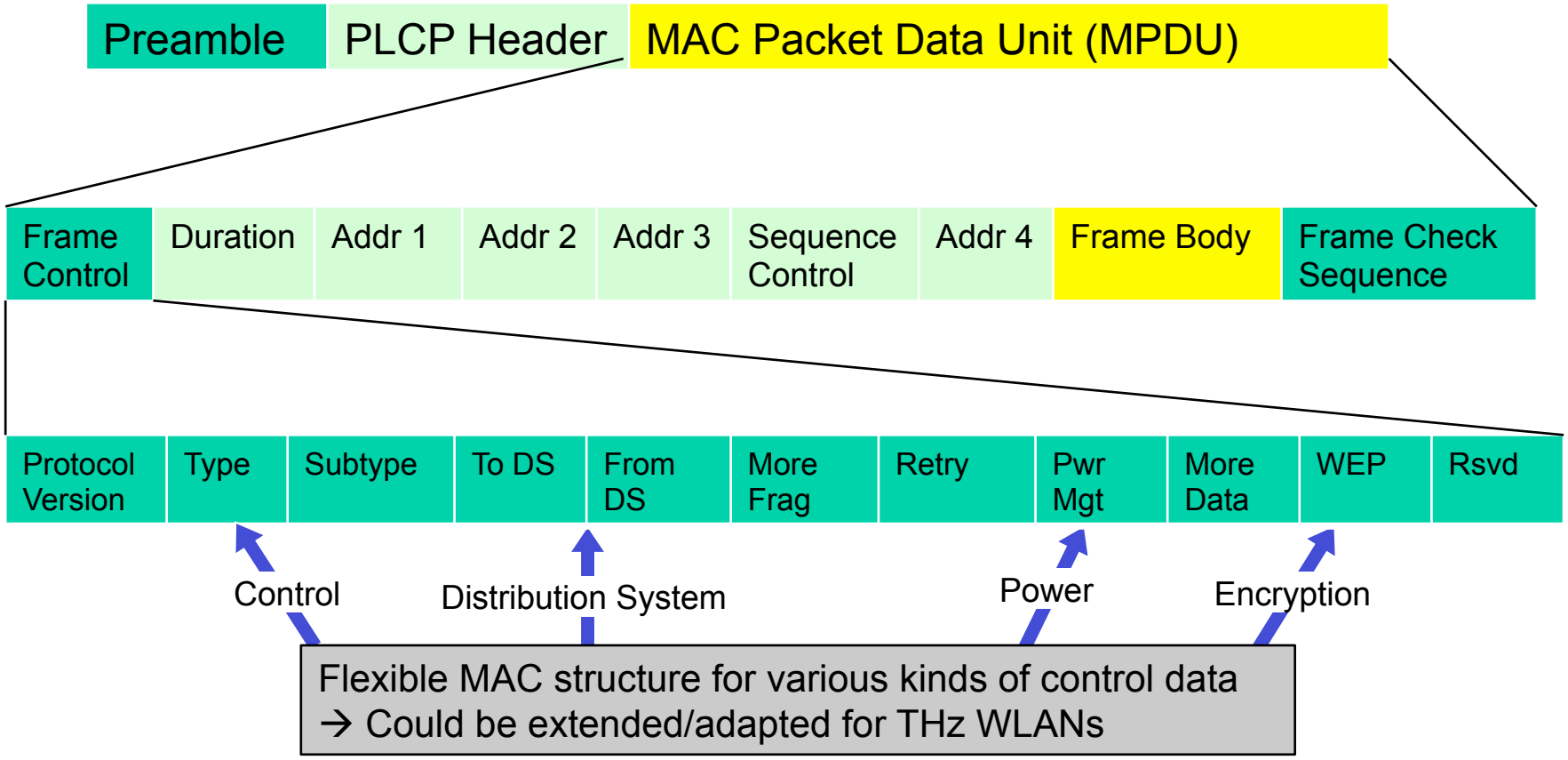
- Physical Layer Convergence Procedure (PLCP): ensures the interoperability of different 802.11 PHY layers with one MAC
- Access scheme: CSMA/Collision Avoidance (CA) with back-off time



→ Severely limits data rates (e.g. 500 Mbit/s PHY → ~50 Mbit/s net)

IEEE 802.11 (2)

- Frame structure of 802.11:



IEEE 802.11 (3)

802.11n

- Multi antenna operation in IEEE 802.11n: MIMO defined in PHY, *not* in MAC layer (Space-Time Block Codes)
- MAC improvements introduced by IEEE 802.11n:
  - Aggregation of MPDUs
  - Block acknowledgement of several MAC frames
  - …

→ Reduction of MAC-induced throughput impairments

802.11ad

- Beamforming support:
  - Sector Level Sweep (SLS)
  - Beam Refinement Protocol (BRP)
- Personal Independent Basic Service Set:
  - Direct connection between two devices without CSMA/CA
  - Third device as control point
  - Access according to coordinated schedule

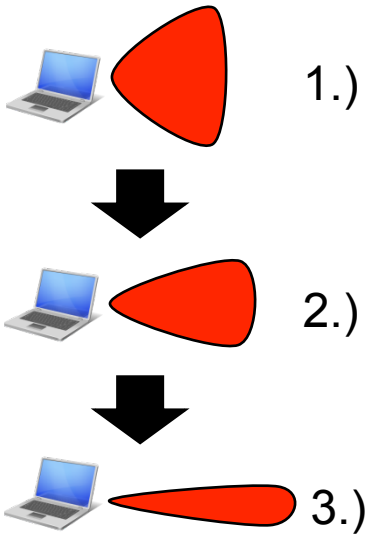
→ Not possible for THz systems due to need for high gain

→ Can deal with directive antenna systems

IEEE 802.15.3c

- Networks organized as piconets (ad-hoc)
  - One node as piconet controller (PNC)
- Hybrid CSMA/CA
  - CSMA/CA for access procedure
  - TDMA for transmission (slots administered by PNC)
- Beamforming: codebook-based approach for antenna array weight vectors (different predefined beams selectable)
  1. Quasi-omnidirectioal patterns (low gain, low directivity)
  2. Sector patterns (mid gain, mid directivity)
  3. Beam patterns (high gain, high directivity)

→ Sequential beam refinement coordinated by PNC



→ Not possible for THz systems due to need for high gain

Comparison of the Standards

Capability	IEEE 802.3	IEEE 802.11n	IEEE 802.11ad	IEEE 802.15.3c
Access				
Data transmission				
Disassociation				
Security				
Roaming				
Power saving				
Channel estimation				
Adaptive modulation				
Beam control				
Coexistence				
Robustness	−−−	+++	+++	++
Overhead	+++	−−−	−−	o

Provided

Not provided

Missing beam-forming support in 802.11n

802.15.3c preferable over 802.11ad due to lower overhead

802.3 appropriate for fixed links with stable, predefined conditions only; very low overhead

Recommendations – Type (a)

Requirements	1.) Fixed links	2.) Data center links	3.) Intra device
Access			
Data transmission			
Disassociation			
Security			
Roaming			
Admission control			
Channel estimation			
Adaptive modulation			
Beam control			
Coexistence			

Necessary

Not necessary

→ Access and trans-mission with a simple proprietary format

→ Hardware encryption without need for authentication

→ Beam selection for data center links (e.g. with meshed networks 802.11s)

Recommendations – Type (b)

Requirements	4.) Kiosk
Access	
Data transmission	
Disassociation	
Security	
Roaming	
Admission control	
Channel estimation	
Adaptive modulation	
Beam control	
Coexistence	

→ Access trigger via convetional WLAN/Bluetooth/UWB/...
→ Transmission in a simple proprietary format or based on 802.3

→ User credential verification in higher OSI layers

Necessary

Not necessary

Recommendations – Type (c)

Requirements	5.) WPAN	6.) WLAN
Access		
Data transmission		
Disassociation		
Security		
Roaming		
Admission control		
Channel estimation		
Adaptive modulation		
Beam control		
Coexistence		

→ WPANs: adoption of 802.15.3c
→ WLANs: 802.11ad or amendment of roaming to 802.15.3c

→ Amendment of access and beam alignment procedure via conventional radio

Necessary | Not necessary

Outline

1. Introduction
2. General MAC Layer Requirements
3. Use-Case-Specific MAC Requirements
4. Suitability of Existing IEEE MAC Protocols
5. **Conclusion**

Conclusion

- Main difference compared to conventional WPANs/WLANs is the high antenna directivity and required steerability

→ MAC layer must encompass beam control as the key component

- Access and beam alignment cannot be realized in THz band

→ Out-band-signaling has to be employed

- Requirements for the MAC layer are highly use-case-dependent

→ Use-case-specific MAC solutions must be chosen

- Suggested MAC layer concepts:
  - *Fixed links, data center, chip-to-chip*: proprietary solution with very low overhead
  - *Kiosk downloads*: link activation via conventional radio system, proprietary format for transmission
  - *WPANs/WLANs*: Access and beam alignment via conventional radio system, adoption of 802.15.3c or 802.11ad for control and transmission

References

- IEEE 802.11-10/0432r0: “PHY/MAC Complete Proposal to TGad”
- K.-W. Chin, D. Lowe: “The IEEE 802.15.3 MAC: Enabling High-Rate Multimedia Applications in Wireless Personal Area Networks”, UoW-WTL-TechReport-3-05, June, 2005.

Technical Expectations Document (TED)

All information contained in this presentation is meant to be included in the technical expectations document 15-11-0745-05-0thz-thz-ig-technical-expectations-document-ted.doc.

Thank you for paying attention.

Dipl.-Ing. Sebastian Priebe
priebe@ifn.ing.tu-bs.de